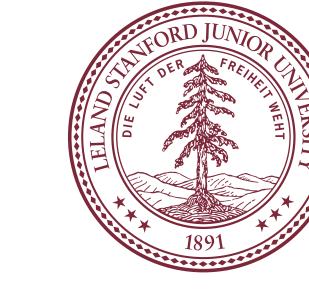# Sources and Fate of *Salmonella* and Fecal Indicator Bacteria in an Urban Creek

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WARNING

THESE WATERS ARE CONTAMINATED AND ARE NOT SUITABLE FOR SWIMMING OR OTHER WATER CONTACT ACTIVITIES

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Abstract

Previous research in Central California found that San Pedro Creek in Pacifica had unusually high levels of *Salmonella*, relative to other nearby waterbodies. The present study investigated the spatial and temporal variability of *Salmonella* and Fecal Indicator Bacteria (FIB) in San Pedro Creek and used human and horse-specific *Bacteroidales* fecal markers to conduct microbial source tracking. Three surveys along San Pedro Creek spanning urban and forested areas were conducted. *Salmonella* was detected adjacent to and downstream of urban land cover, but not adjacent to forested land cover. No human or horse-specific *Bacteroidales* fecal markers were detected. Enterococci and *Salmonella* were positively correlated. Additionally, concentrations of *Salmonella* and enterococci were significantly higher during a survey conducted in wet weather compared to those conducted in dry weather. Two locations where *Salmonella* was consistently detected were sampled hourly for 25 hours and a mass-balance model was applied to determine field-relevant light and dark inactivation rates for *Salmonella*, enterococci, and *Escherichia coli*. Sunlight inactivation did not appear important in modulating concentrations of *Salmonella*, but was important in modulating both enterococci and *E. coli* concentrations. Dark inactivation was important for all three organisms. Inclusion of a zeroth order source term within the creek was needed to explain the dynamics of *E. coli*, suggesting this organism may grow within the creek itself.
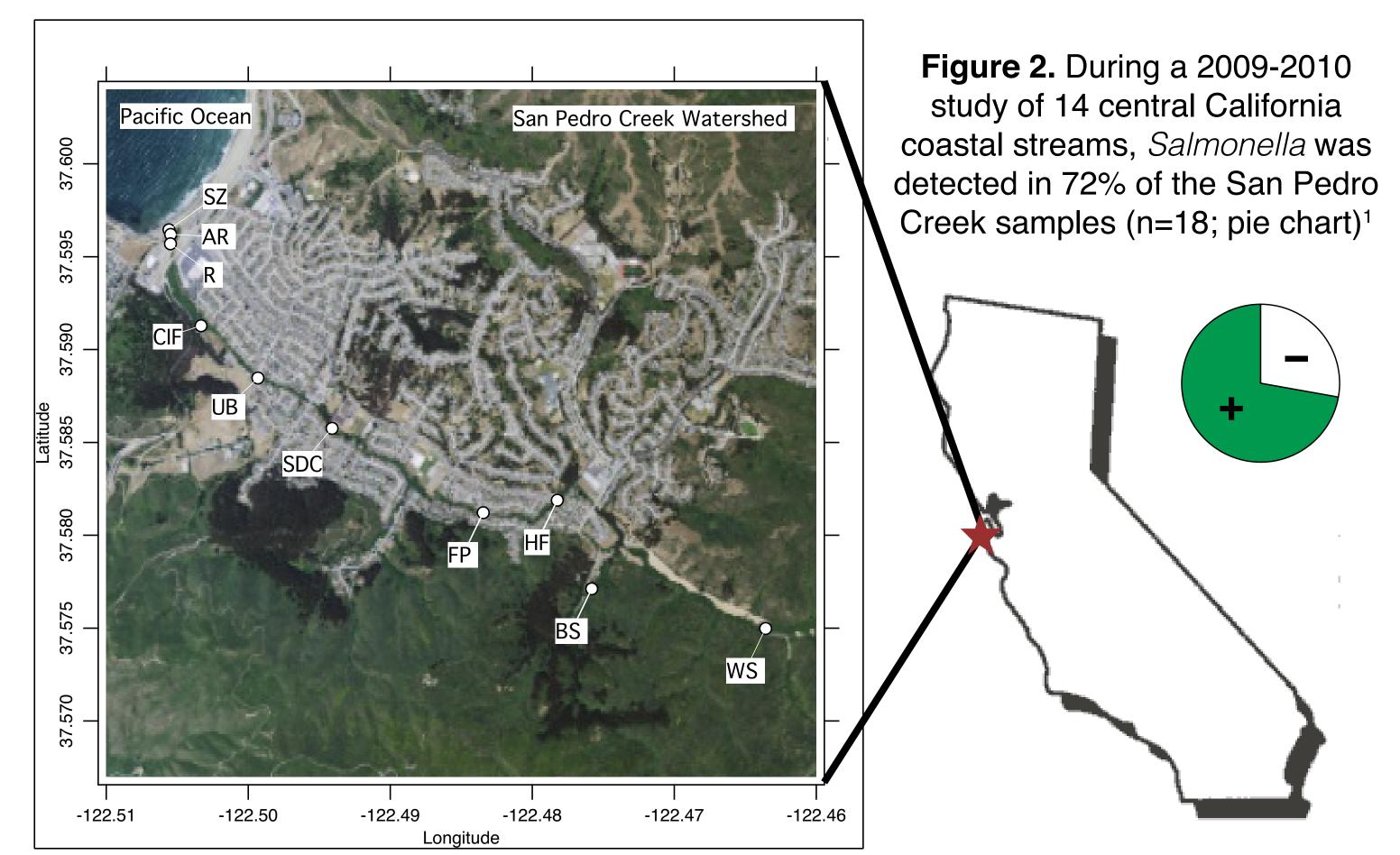
Study Design

Figure 1. San Pedro Creek is a perennial creek draining a 20.7 km² watershed.

Figure 2. During a 2009-2010 study of 14 central California coastal streams, *Salmonella* was detected in 72% of the San Pedro Creek samples (n=18; pie chart)[1]

Spatial Surveys
• June 29, 2009
• Sept. 29, 2009
• Feb. 24, 2010
• 10 sites (Figure 1)

Temporal study
• May 23 4:00 h to May 24, 2010 4:00 h
• sites UB and R

Microbiological Assays
• enterococci (CFU/100 ml)
• *E. coli* (CFU/100 ml)
• *Salmonella* (MPN/1 L)[1]
• human-specific *Bacteroidales* (+/-)
• horse-specific *Bacteroidales* (+/-)

Study Goals:
1) Identify locations along San Pedro Creek where inputs of FIB and *Salmonella* occur

2) Determine whether humans or horses contribute *Salmonella* or indicator bacteria to the creek using *Bacteroidales* host-specific fecal markers

3) Determine field-relevant dark and light inactivation rates of indicator bacteria and *Salmonella* within the creek using a mass-balance modeling approach using:

$$v_x \frac{dC}{dx} = -kC + S$$

C= concentration; x=distance along creek; v=longitudinal velocity; k=first order decay rate; S=source

References

1) S. P. Walters, A. L. Thebo and A. B. Boehm, Water Research, 2011, 45, 1752-1762.
2) A. E. Bernhard and K. G. Field, Applied and Environmental Microbiology, 2000, 66, 4571-4574.
3) L. K. Dick, A. E. Bernhard, T. J. Brodeur, J. W. Santo Domingo, J. M. Simpson, S. P. Walters and K. G. Field, Applied and Environmental Microbiology, 2005, 71, 3184-3191.
4) S. P. Walters, N. Gonzales-Escalona, I. Son, A. L. Thebo and A. B. Boehm, 2011, in preparation.
5) J. Davis and C. Chan, San Pedro Creek Watershed Coalition Bacterial Analysis Project, 2008.
6) A. B. Boehm, K. M. Yamahara, D. C. Love, B. M. Peterson, K. McNeill and K. L. Nelson, Environmental Science & Technology, 2009, 43,

Results

Figure 3. Spatial survey results for June (top), Sept (middle) and Feb (bottom) creek surveys. Open circles indicate measurements below our limit of detection (0.75 MPN/L).
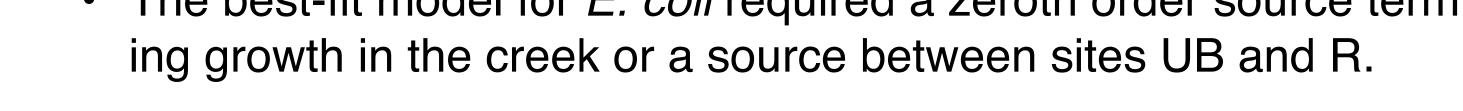
Spatial Results

1) *Salmonella* was consistently detected along the urban reach of San Pedro Creek and never in the undeveloped upper watershed (Figure 3).
   • During dry weather *Salmonella* was found primarily between sites UB and R.
   • During wet weather, *Salmonella* was detected at all sites downstream of urban development, even in the surf zone.
   • *Salmonella* and enterococci concentrations were correlated with each other, indicating that, in this watershed, the presence of enterococci is a good indicator of *Salmonella* presence.

2) The human- and horse-specific markers were not detected in any samples suggesting that sources are non-human, non-equine, urban sources.

Temporal Results

3) Results show evidence of sunlight inactivation for enterococci and *E. coli* but not *Salmonella* (Figure 4).
   • The best-fit model for *E. coli* required a zeroth order source term suggesting growth in the creek or a source between sites UB and R.

Table 1. Summary of best fit model parameters.

Organism	k_{dark} (min⁻¹)	k_{sun} (min⁻¹ l⁻¹)	Source (CFU/100 mL/min)
enterococci	4.4 x 10-3	1 x l⁻⁴	0
E. coli	7.2 x 10-2	2.6 x 10-3	12.6
Salmonella	1 x 10-3	0	0

Human Health Risk

Several serotypes of *Salmonella* known to cause human illness were found in San Pedro Creek including *S. enterica* Typhimirium, Enteritidis, and Heidelberg.[4]
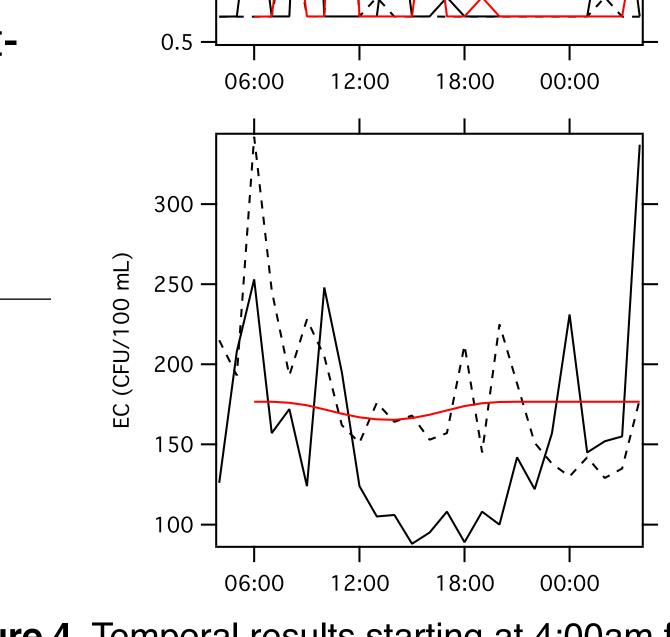

Figure 4. Temporal results starting at 4:00am for enterococci (top), *Salmonella* (middle) and *E. coli* (bottom) at the downstream site (UB) (black line), the upstream site (R) (dotted line), and the best-fit model (red line) for site R given site UB.

Conclusions & Future Work

• While the health risk associated with the levels of *Salmonella* in San Pedro Creek are low, serotypes of *Salmonella* known to cause illness in humans were detected in the creek. Thus, exposure to the creek water, including the creek water discharged into the surf zone of Pacifica State Beach, should be avoided.

• Previous work in this watershed suggested that birds were a main source of *E. coli*, with additional contributions from dogs, horses, and humans.[5] Future work that applies avian, dog and human-specific source tracking methods will allow additional insight into the important sources of FIB and *Salmonella* in the creek.